DRILLED PIER INSPECTION MANUAL

GEOTECHNICAL ENGINEERING UNIT
OCTOBER 2011 – 2nd EDITION

TABLE OF CONTENTS

I. Introduction

A. Scope

The intent of this manual is to provide North Carolina Department of Transportation (NCDOT) inspector personnel, as well as other inspectors representing the NCDOT, with guidelines and information for inspecting drilled pier construction. Drilled piers are also commonly referred to as "drilled shafts" and "caissons". This manual is also helpful for training other construction personnel, such as resident engineers, assistant resident engineers and area bridge construction engineers in drilled pier construction and inspection.

B. Limitations

A large part of this manual is derived from the standard NCDOT Drilled Piers Special Provision. This manual may or may not be applicable to drilled piers constructed under other Drilled Piers Special Provisions. In some cases, such as a project with a large quantity of drilled piers, the Drilled Piers Special Provision may be project specific. Also, the standard Drilled Piers Special Provision is revised regularly. As a result, before applying this manual in its entirety to any project, the project Drilled Piers Special Provision should be compared with the standard Drilled Piers Special Provision in the Appendix for differences (compare dates of each provision).

Drilled pier construction practices vary widely across North Carolina depending on the subsurface conditions and the drilling contractor. Unexpected and unanticipated problems can occur. This manual is not intended to be all-inclusive. When these situations arise, questions should be directed to the area bridge construction engineer and the Geotechnical Engineering Unit. The Geotechnical Engineering Unit may be contacted at:

Geotechnical Engineering Unit
1020 Birch Ridge Drive
Raleigh, NC 27610
(919) 250-4128
(919) 250-4119 (Fax)
Website - http://www.ncdot.org/doh/preconstruct/highway/geotech/
State Geotechnical Engineer: Njoroge Wainaina, P.E.

II. General

A. Drilled Pier Definition

The FHWA drilled shaft manual (Publication No. FHWA-IF-99-025) describes drilled piers as "a deep foundation that is constructed by placing fluid concrete in a drilled hole." This FHWA manual also notes that "reinforcing steel can be installed in the excavation, if desired, prior to placing concrete." A schematic example of a typical drilled pier is shown in Figure 1. This figure also shows loading conditions, end bearing, skin friction and lateral resistance.

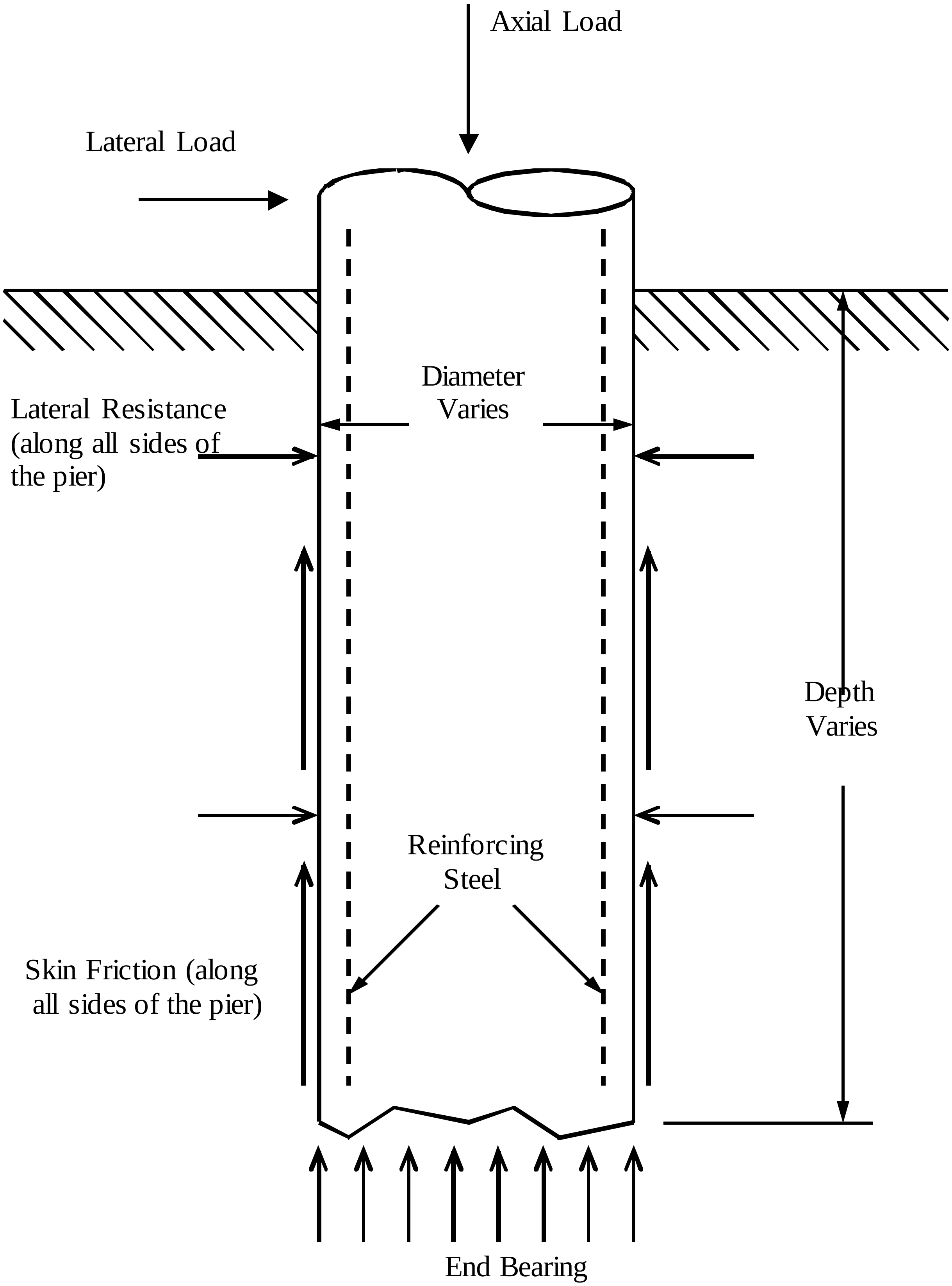

FIGURE 1 – Schematic of Typical Drilled Pier

B. Loads (See Figure 1)

Axial loads are primarily due to the weight of the bridge structure and the traffic on the structure. Uplift, downdrag and lateral loads that result in overturning also cause axial loads. Lateral loads are caused by a wide variety of forces such as stream flow, wind, ship impact, earth pressures, temperature changes (thermal and shrinkage forces), earthquakes, etc. Drilled piers are designed for both axial and lateral loads. The axial loads are supported by end bearing, skin friction or a combination of the two. Skin friction is developed as a result of the bond between the concrete and the soil/rock along the sides of the drilled pier. The lateral loads are primarily supported by lateral resistance of the soil/rock. Lateral resistance is developed when the lateral loads cause the drilled pier to push against the soil/rock along the sides of the drilled pier.

C. Drilled Pier Construction Sequence Plan

For the purposes of this manual, the standard NCDOT Drilled Piers Special Provision in the Appendix is referred to as the “special provision”. The special provision requires the drilling contractor to develop a drilled pier construction sequence plan for each project (Section 1.0, Item C). The primary purpose of this plan is to propose the method of drilled pier construction and insure compliance with the special provisions. The method to construct drilled piers can vary depending on the drilling contractor, subsurface conditions, site conditions and drilled pier design. For instance, construction of a drilled pier in a body of water would be different than construction of a drilled pier in a highway median. In the same manner, a 60 foot (18 meter) long drilled pier would likely be constructed differently than a 20 foot (6 meter) long drilled pier. The drilled pier construction sequence plan should also include work experience, personnel and equipment listings.

D. Drilled Pier Preconstruction Conference

After the drilled pier construction sequence plan is approved and before beginning drilling, a drilled pier preconstruction conference should be scheduled. At a minimum, the general contractor, drilled pier subcontractor superintendent, resident engineer, bridge inspector and area bridge construction engineer should attend the meeting. A representative from the Geotechnical Engineering Unit may attend if the GEU believes it is necessary or the area bridge construction engineer can not attend. It is desirable to hold the conference at the project site in order to help resolve site specific issues while all the parties are in attendance.

The primary purpose of the drilled pier preconstruction conference is to discuss the construction and inspection of the drilled piers. Topics for discussion may include the following:

- Approved drilled pier construction sequence and review from the Geotechnical Engineering Unit
- Excavation methods
- Permanent and temporary casing
- Casing sizes, lengths, installation and removal
- Cleaning method and inspection

- Bearing inspection
- Subsurface profile and expected rock elevations
- Concrete placement
- Environmental issues including spoils and concrete handling/disposal
- Inspection forms
- Sequencing and scheduling

III. Construction

A. Methods of Excavation

Section 2.0 of the special provision states "Stabilize all drilled pier excavations with steel casing and/or bentonite slurry except, as approved by the Engineer, the portions of the excavations in rock….". The special provision does not allow the use of slurry without steel casing. If slurry is used and permanent casing is not, the special provision requires temporary casing a minimum of 10 feet (3 meters) long at the top of the excavation. When the use of slurry is not required or prohibited by the plans, the drilling contractor may choose to use only steel casings or slurry with steel casings to stabilize the drilled pier excavation. When the use of slurry is prohibited by the plans, the drilling contractor is required to use only steel casings.

The casing diameter normally refers to the outside diameter. The special provision allows for the drilled pier diameter in rock to be 2 inches (50 mm) smaller than the design drilled pier diameter. This will occur if the drilling contractor stabilizes an excavation to rock with casing size equal to the design drilled pier diameter. In order to extend the excavation into rock below the bottom of the casing, the rock drilling tools pass through the casing and excavate a smaller diameter hole. The smaller drilled pier diameter in rock is considered in design even though the plans show the design drilled pier diameter. A smaller design drilled pier diameter will also occur when using slurry and permanent casing with an outside diameter equal to the design drilled pier diameter.

1. Steel Casing

Permanent casings remain in place and are used for drilled piers in standing water, soft collapsing soils or on a bank of a body of water. Temporary casings are removed during the concrete pour and are used to keep the excavation open and also to protect personnel entering the excavation. The required casing wall thickness is in Section 2.0, Item A of the special provision. Figure 2 is a picture of a steel casing.

The use of permanent casing is controlled by one of the following notes on plans.
"Permanent steel casing is not required for drilled piers at Bent No. ___."
"Permanent steel casing is required for drilled piers at Bent No. ___ and the casing shall not extend below elevation ___ without the Engineer's permission."
"Permanent steel casing may be required for drilled piers at Bent No. ___. If required, the casing shall not extend below elevation ___ without the Engineer's permission. The need for permanent steel casing will be determined by the Engineer."

FIGURE 2 – Steel Casing

When permanent casing may be required, the resident engineer and the area bridge construction engineer determine the need for permanent casing based upon the specific site conditions at the time of construction. The notes on plans provide an elevation that the permanent casing may not extend below. The main reason for this elevation is that the skin friction is significantly less in the permanent casing zone because the concrete is not in direct contact with the soil/rock. Consequently, if the permanent casing is extended below the elevation shown on the plans, the axial capacity of the drilled pier is reduced. Sometimes, the permanent casing is not stable at or above the elevation shown on the plans and the drilling contractor may propose lowering the casing. Regardless of the situation or circumstances, the area bridge construction engineer and the soils engineer should be contacted to discuss all requests to extend any permanent casings below the elevation shown on the plans.

The special provision requires that permanent casing be in contact with "undisturbed material". One reason for this requirement is that the permanent casing may extend below the design scour elevation, which is not shown on the plans. The soils engineer assumes that the material below the design scour elevation will provide lateral resistance. If the permanent casing is not in contact with undisturbed material, the lateral load capacity of the drilled pier is reduced. Another reason for this requirement is that if the permanent casing is not in contact with undisturbed material, longer permanent casing may be required for casing stability, which may cost more since permanent casing is paid for on a unit price basis. Installing the permanent casing against undisturbed material typically requires vibrating, driving or screwing the casing into place before drilling through the casing. Figure 3 is a picture of a "twister" used to screw casing into place by interlocking the twister into the slots at the top of the casing (see slots in Figure 2). Figure 4 is a picture of a vibratory driver/extractor used to vibrate casing in and out.

FIGURE 3 – Twister

The special provision does not direct the drilling contractor on how to install steel casings. Ideally, all permanent and temporary casings should be installed before drilling through them. However, due to subsurface conditions, equipment limitations and drilling contractor preference, casings are often installed by predrilling without casing or slurry and then placing the casing into the excavation. Predrilling may be used to install casing through very dense or stiff soils, rock and boulders or because the contractor's drill rig can only accommodate a certain length of casing extending out of the excavation so the remaining portion of the casing must be placed in the excavation. Predrilling can result in an unstable, caving and collapsing excavation. The Geotechnical Engineering Unit must approve predrilling for permanent casings because the special provision requires that permanent casing be against undisturbed material. Typically, the drilled pier construction sequence plan describes the method of casing installation and if predrilling is proposed, it will be addressed in the sequence review.

FIGURE 4 – Hydraulic Vibratory Driver/Extractor

In some cases, for long drilled piers or when the permanent casing does not extend to rock, casings are telescoped because a single piece of casing is too long to handle. Telescoping casing results in multiple levels of casing (usually, three levels or less) with the smallest diameter (design diameter) on the inside and the largest diameter on the outside. The drilled pier inspection form for the casing method shows a diagram of three levels of telescoping casing. Typically, casing diameters vary by 6 inches (150 mm) per level. The Association of Drilled Shaft Contractors (ADSC) recommends a minimum casing overlap of 1 foot (300 mm) in their down-hole entry manual; the Geotechnical Engineering Unit recommends a minimum casing overlap of 2 feet (600 mm). Depending on the actual site conditions, more than 2 feet (600 mm) may be required such as in caving soils or when water flows through the overlap. Water flowing through the overlap is an unsafe condition for entry into the excavation, may erode the side walls of the excavation and contaminate the concrete during placement.

Section 2.0 of the special provision states that "Temporary steel casings that become bound or fouled during pier construction and cannot be practically removed constitute a defect in the drilled pier". If this occurs, contact the area bridge construction engineer and the Geotechnical Engineering Unit to discuss the situation.

2. Mineral Slurry
   The use of mineral slurry may be controlled by one of the following notes on plans.
   "Slurry construction shall not be used for this project."
   "Slurry construction shall be used for this project. See Drilled Piers Special Provision."

   If neither one of these notes is shown on the plans, the drilling contractor may choose to use only steel casings or slurry with steel casings to stabilize the drilled pier excavation. In general, the first note is used in the western part of the state where rock is relatively shallow and the second note is used in the eastern part of the state for drilled piers in soil. The soils engineer will require slurry based upon the subsurface conditions (caving soils?), drilled pier lengths and constructability concerns. The drilling contractor may choose slurry based upon constructability and preference. Slurry is not used exclusively in lieu of casing because it is generally more expensive and time consuming.

   The slurry should always be introduced before drilling below the bottom of the permanent or temporary casing. Drilling below any casing without stabilizing the excavation can result in a collapsed excavation.

   Slurries are defined as mineral slurries, polymer slurries or blended slurries. The special provision specifically requires the use of bentonite slurry, which is a mineral slurry. Bentonite is a type of powdered clay that when mixed with water, forms microscopic, plate-like solids. However, in order for these "plates" to be formed, the water must first hydrate the bentonite. The electrically charged water surrounding the plates cause the plates to repel each other and keep the bentonite in suspension. The bentonite will not be effective until hydration has occurred. As a result, the special provision requires hydration of the bentonite for a minimum of 24 hours before being introduced into the drilled pier excavation. Mixing slurry in the excavation is prohibited.

   The drilled pier excavation is stabilized when the bentonite plates are deposited on the side walls of the excavation as the bentonite slurry flows out. This action, which is termed "filtration", can only occur if the level of the slurry inside the excavation is higher than the water elevation outside the excavation such that the higher pressure inside the excavation forces the slurry out. This is the reason for the requirement in Section 2.0 of the special provision to "Maintain the slurry in the pier excavation at a level not less than 5 feet or the drilled pier diameter (whichever is greater) above the highest piezometric pressure head along the depth of the pier." Normally, the highest piezometric pressure head is the high tide elevation, the static water elevation or the groundwater elevation. If the slurry level is not continuously maintained in accordance with the special provision, the excavation could collapse due to water flowing into the excavation rather than slurry flowing out. When the required slurry level is above the ground surface or when drilling over water, the casing is typically extended to maintain the slurry pressure head and then removed during pouring for piers with temporary casing or cut off after the concrete reaches strength for piers with permanent casing.

a. Time and Agitation Requirements
The deposit of bentonite plates on the side walls of a drilled pier excavation is referred to as the formation of a "mudcake". Without proper and frequent agitation, the mudcake can become too thick and will reduce the skin friction and therefore, the axial capacity of the drilled pier. Consequently, the special provision requires the following:
- Agitate the slurry in the drilled pier excavations a minimum of every 4 hours and
- Do not allow an excavated slurry shaft below the steel casing to go unagitated overnight.

It is important to note that it is always in the department's best interest to complete a slurry drilled pier within a 24 hour time limit. Consequently, the special provision requires the drilling contractor to "Adjust the excavation operations so that the maximum time the slurry is in contact with the sidewalls of the uncased portions of the drilled pier excavation (from time of drilling to completing concrete placement) does not exceed 24 hours". If the 24 hour time limit is exceeded, the special provision describes what is required depending on how much time has elapsed. If less than 3 days and more than 24 hours has elapsed, overreaming with an approved method is required. If three days elapses, the special provision requires the contractor to enlarge the entire drilled pier (including the casing) by a minimum of 6 inches (150 mm).

B. Dewatering Requirements
Per the special provision, if the tip of a drilled pier is in rock, the excavation must be dewatered "to the satisfaction of the Engineer". Dewatering the excavation will generally allow the inspector to perform a more thorough inspection by entering the excavation. In some situations, such as sites with a high groundwater table or long piers in deep water or loose soil, dewatering the excavation may not be feasible. If the drilling contractor proposes to maintain a wet hole even though the tip is in rock, the Geotechnical Engineering Unit should approve this in the drilled pier construction sequence review. If a drilled pier excavation is not dewatered, the drilled pier construction sequence will typically include procedures for cleaning and inspection from the top of the hole.

C. Cleaning Requirements
The best method for cleaning the bottom of a drilled pier excavation is by hand. However, the excavation must be dewatered to be hand cleaned. Sometimes, drilled pier excavations can not be dewatered as described above. In other situations, the drilling contractor is not required to dewater the excavation such as when the tip is in weathered rock or soil. Even if the excavation is dewatered, it may not be hand

cleaned due to unacceptable gas/oxygen levels or because it is not the drilling contractor's policy to enter an excavation. In any case, the special provision does not require hand cleaning. However, Section 3.0 of the special provision does require that the pier excavation bottom be cleaned with a cleanout bucket **and** a submersible pump or an airlift if the excavation bottom is not hand cleaned. Figure 5 is a picture of a submersible pump. Figures 6 and 7 illustrate the use of an airlift. An airlift is easier to use, faster when compared with a submersible pump and generally used only for excavations in rock because it can over excavate a soil bottom.

FIGURE 5 – Submersible Pump

Some drilling contractors will attempt to clean a drilled pier excavation bottom with only a cleanout bucket. Not only is this a violation of the special provision, subsequent visual inspections have proved that this practice can leave large amounts of sediment around the edges of the bottom of the excavation.

D. Temporary Casing Removal

The special provision does not explicitly direct the drilling contractor on how to remove telescoping temporary casing. However, the special provision states "Do not remove temporary casing until the level of concrete within the casing is in excess of 10 feet (3 meters) above the bottom of the casing being removed." In addition, the special provision states "Maintain the concrete level at least 10 feet (3 meters) above the bottom of innermost casing throughout the entire casing extraction operation, except when concrete is at or above the top of drilled pier elevation. Sustain a sufficient head of concrete above the bottom of casing to overcome outside soil and

FIGURE 6 – Airlift with Discharge

FIGURE 7 – Withdrawing Airlift

water pressure." Based upon these requirements, a casing may not be removed unless 10 feet (3 meters) of concrete is in direct contact with the inside of the innermost casing at all times. Drilling contractors may prefer to remove outer casings before removing the innermost casing; however, this practice leaves the side walls of the drilled pier excavation unsupported allowing for potential collapse. Even if only partial collapse occurs or the collapsed soil is moved back into place by the rising concrete, the side walls may no longer provide the lateral resistance and skin friction required for design. Consequently, removal of temporary outer casings prior to removal of temporary inner casings is not recommended.

E. Reinforcing Steel and Tolerances

Unless the drilled pier excavation is cased to rock, immediate placement of the reinforcing steel and the concrete is required after the inspector approves the excavation. If the excavation is cased to rock and the excavation is relatively shallow, drilling contractors may choose to excavate and pour more than one pier at a time. Per the special provision, all reinforcing steel should be cross-tied with double wire at each intersection of the vertical and spiral bars. The complete rebar cage should be lifted and placed in the excavation such that racking and cage distortion does not occur. Longer cages will require multiple pick up points such as shown in Figure 8.

FIGURE 8 – Drilled Pier Rebar Cage

Reinforcing steel must have a minimum of 4 inches (100 mm) of clearance between the edge of the spiral and the outside edge of the pier. Additional clearance is normally included in the plans to extend the spiral into the column or protect against corrosion. The special provision requires maintaining a minimum 4 inch (100 mm) clearance with plastic spacer wheels spaced a minimum of every 10 feet (3 meters) along the rebar cage. The most common type of plastic spacer wheel is a "Shaftspacer" manufactured by Foundation Technologies, Inc. The special provision also requires that the rebar cage be raised off the bottom of the excavation with plastic bolsters. Foundation Technologies also manufacturers the most common type of plastic bolster called a "BarBoot". Figure 9 is a picture of a reinforcing cage with BarBoots and Shaftspacers. The picture shows two sizes of Shaftspacers; the smaller of which is connected to the cage with offset hairpins which allows for different clearances other than standard size spacer wheels.

FIGURE 9 – Shaftspacers and BarBoots

There is 2 inches (50 mm) of clearance on a typical bridge column. When the drilled pier connects directly to the column instead of a footing or a cap, it is possible for the drilled pier excavation and rebar cage to be in tolerance and the column out of location. Since the drilled pier diameter is typically 6 inches (150 mm) larger than the column, it may be possible to adjust the reinforcing steel such that the column is in the correct location or the column location may be acceptable without any adjustment with sufficient clearances in the cap. Alignment of the rebar cage is more difficult for oversize casings such as those used for telescoping casing because the spacer wheels are not against the sides of the excavation at and near the top of the hole. The special provision requires the following tolerances for drilled piers:

- Excavation no more than 3 inches (75 mm) from the location shown on the plans
- Axis within 1 % plumb
- Bottom of excavation stepped no more than 12 inches (300 mm)
- Top of pier elevation between 1 inch (25 mm) above and 3 inches (75 mm) below elevation shown on the plans (or revised elevation per engineer)

Drilled pier reinforcing steel is designed with an extra 3 feet (1 meter) of length because it is difficult to excavate to the exact plan tip elevation. Normally, drilled piers are excavated to slightly below the plan tip elevation. If the drilled pier connects directly to the column, the extra rebar cage length is accounted for with a varying splice length. If the drilled pier connects to a cap or a footing, the extra rebar cage length is usually cut off after the precise tip elevation is known. If the tip elevation is lowered due to poor bearing conditions or for other reasons, the extra reinforcing steel should be used for the additional drilled pier length. If the tip elevation is lowered more than 3 feet (1 meter), the situation should be discussed with the area bridge construction engineer and the Geotechnical Engineering Unit.

F. Methods of Concrete Placement

The method of concrete placement depends on the water inflow rate after all the pumps have been removed from the drilled pier excavation. If the inflow rate is more than 6 inches (150 mm) per half-hour, a wet pour is required. Otherwise, a dry pour is acceptable. This check is extremely critical. Experience indicates that the majority of problems with drilled piers are the result of forcing a dry pour. Figure 10 is a picture of a wet pour with a tremie, hopper and a concrete bucket.

Sometimes, the drilling contractor will "break loose" the temporary casing before placing concrete in order to minimize the chances of the casing getting stuck. This practice can change the conditions in the hole and significantly increase the water inflow rate. If this occurs or any other condition changes that significantly increases the flow of water into the excavation, the water inflow rate should be re-checked to evaluate the type of pour required.

1. Free Fall

   For dry placement of concrete, the concrete may be placed by free fall down the center of the drilled pier excavation if the depth is 60 feet (18.3 meters) or less. Otherwise, the concrete must be either tremied or pumped such that the free fall height does not exceed 60 feet (18.3 meters).

2. Tremie and Pump

   For wet placement of concrete, Section 6.0 of the special provision does not allow the use of a tremie with temporary casing. This is because contractors do not typically have two cranes or a crane with the drill rig on-site and problems can

FIGURE 10 – Wet Pour

occur when the temporary casing is removed and the tremie is supported with the same equipment.

Unless approved otherwise, all tremies should be sectional type. Figure 11 is a picture of sectional tremie with 10 foot (3 meter) sections. Typically, a solid tremie will be approved for short drilled piers or when using sectional temporary casing.

For wet placement of concrete, care should be taken when introducing the concrete into a drilled pier excavation with a pump. If the concrete is pumped too fast at the beginning of placement, the concrete is not able to displace the water or slurry around the bottom of the pier and reduced end bearing capacity may result. Initially, the tremie or pump pipe is lowered to the bottom of the excavation. As the concrete placement continues, the tremie or pump pipe may be removed provided the tremie or pump pipe remains embedded in the concrete a minimum of 10 feet (3 meters). In accordance with the special provision, if the tremie or pump pipe pulls out of the concrete for any reason during the pour, concrete placement must be restarted with a steel capped tremie or pump pipe. Otherwise, water or slurry will become trapped in the pier when the tremie or pump pipe is reinserted into the concrete. When using a pump, it is also important to minimize "jumping" of the pump pipe (pump pipe pulling in and out of the concrete) by controlling the pump stroke pressure.

FIGURE 11 – Sectional Tremie

3. Discharge Control
   A discharge control, commonly called a "pig" or a "rabbit", is used to prevent concrete contamination when the tremie or pump pipe is initially placed in the drilled pier excavation. This device keeps the water or slurry separated from the concrete as the concrete is pushed through the tremie or pump pipe to the bottom of the excavation. The discharge control must be placed at the top of the tremie or pump pipe, not the bottom. The Geotechnical Engineering Unit will approve the type of discharge control in the drilled pier construction sequence review. In general, the discharge control should be solid, float and of such a consistency that it will not cause a defect if it remains in the pier. Figure 12 is a picture of a foam pig.

G. Environmental Issues
   Many projects have environmental requirements relating to drilled piers. The majority of these conditions concern handling of spoils and concrete. However, not all environmental issues relating to drilled piers are addressed by the permits. For example, leaking drill rigs may not be expected but should be prohibited when working in high quality waters from causeways or temporary work bridges. The environmental permit requirements are generally more common and specific on projects where it is known that drilled piers and slurry will be used. The most common requirements include turbidity curtains and the containment and off site disposal of spoils and/or slurry. Section 2.0 of the drilled piers special provision requires that the containment and disposal of slurry and excavated materials

FIGURE 12 – Foam "Pig"

contaminated with slurry be in accordance with "all applicable local, state and federal regulations, as well as with the environmental permits of the project". For any drilled pier project, the permits should be reviewed prior to beginning construction for requirements that affect the drilled pier construction.

H. Pay Items

The standard pay items associated with drilled piers are listed below.

- ___ Dia. Drilled Piers in Soil
- ___ Dia. Drilled Piers Not in Soil
- Permanent Steel Casing for ___ Dia. Drilled Pier
- CSL Tubes
- Crosshole Sonic Logging
- SPT Testing
- SID Inspection

The definitions (method of measurement and basis of payment) of these pay items are described in either the Drilled Piers Special Provision or the Crosshole Sonic Logging Special Provision. Reinforcing steel is paid for separately and is not part of these pay items. The last three pay items listed above are methods of testing drilled piers and are described later in this manual.

Section 9.0 of the special provision defines "Drilled Pier Not in Soil" as where non-soil material requires a rock auger penetration rate of less than 2 inches (50 mm) per 5 minutes of drilling at full crowd force and coring, air tools, etc. to advance the excavation. A rock auger is distinguished by the hard-surfaced, conical teeth. Figure 13 is a picture of a rock auger. Sometimes, the contractor is paid for drilled pier not in soil even though the excavation is not in rock. For example, if an excavation in boulders requires tools other than a soil auger, the drilled pier not in soil pay item may be justified. The elevation of drilled pier not in soil may vary depending on the condition and type of drilling equipment used and the subsurface conditions encountered. For this reason, the elevation of drilled pier not in soil should be determined for each excavation and each drill rig based upon the criteria in the special provision. Determining this elevation properly in weathered rock is critical. Large overruns can occur in weathered rock due to variable weathering and drilling equipment. If a large overrun or underrun is foreseen or occurs, contact the area bridge construction engineer and the Geotechnical Engineering Unit.

FIGURE 13 – Rock Auger

IV. Inspection

Just as methods for constructing drilled piers vary around the state, the methods for inspecting drilled piers vary around the state. The Geotechnical Engineering Unit is always available to provide assistance in inspection. Quality inspection requires attention to details. What may appear as relatively minor can have a major impact on the drilled pier construction or design. Most drilled piers are designed for less than 1 inch (25 mm) of movement, both horizontally and vertically. During design, it is assumed that the drilled piers will be constructed in accordance with the special provision and the plans and that the conditions encountered will be similar to those found during the subsurface investigation. Communication between the field personnel and the soils engineer is critical. The soils engineer is relying on the inspector to verify the subsurface conditions and insure the drilled piers are constructed as planned. All changes to or violations of the special provisions, plans or drilled pier construction sequence plan should be discussed with the area bridge construction engineer and the Geotechnical Engineering Unit. It is important to note that it is considerably more expensive both in time and cost to investigate and correct a defective drilled pier after the concrete has hardened than it is to remove fluid or green concrete and start over.

A. Inspector Responsibilities

- Check for compliance with special provision
- Verify pier location layout
- Measure and verify equipment and tools
- Compare subsurface conditions from drilling vs. subsurface information (boring logs)
- Confirm bearing and cleanliness requirements
- Verify and record pay items

It is important that the inspector be at the hole during concrete placement. The vast majority of problems with drilled piers occur during pouring and the inspectors' observations are critical. It is strongly recommended that additional inspection personnel perform the concrete testing while the primary inspector observes the concrete pour.

B. Checklist

- Subsurface information
- Plans
- Drilled Piers Special Provision (for the specific project)
- Approved drilled pier construction sequence and review from the Geotechnical Engineering Unit
- Drilled Pier Inspection Manual
- Safety equipment as detailed in Section C
- Testing equipment as detailed in Sections D, E and F

Per the special provision, the contractor is required to provide all the necessary equipment to safely inspect the drilled pier excavation.

C. Down-hole Inspection Safety

The inspector can perform a more thorough inspection by entering the excavation. As a result, the Geotechnical Engineering Unit encourages down-hole inspection whenever it is possible and safe. However, it is not required and safety is the first priority. The Geotechnical Engineering Unit does not recommend down-hole inspection for drilled piers greater than 60 feet (18 meters) in length. Policies and levels of comfort regarding down-hole inspection vary between divisions, resident offices and individual inspectors. Policies for entering drilled pier excavations vary among drilling contractors depending on their drilling methods, the subsurface conditions they normally encounter and the areas of the state they typically work in. Even if a drilling contractor will not enter a drilled pier excavation, this does not preclude the inspector from entering the excavation.

An inspection casing is a steel casing that extends from the top of the excavation to the bottom such that the entire length of the excavation including the portion in rock is cased and only the bottom of the excavation is exposed. The diameter of an inspection casing is typically 6 inches (150 mm) smaller than the smallest temporary casing used. If the inspector prefers to use an inspection casing, the contractor is required to provide one.

The Association of Drilled Shaft Contractors (ADSC) published a down-hole entry manual in 1996. A copy of this manual is included in the Appendix and it should be reviewed prior to performing down-hole inspections. When performing a down-hole inspection, the following safety guidelines should be strictly followed.

- Lower all equipment into the excavation with or prior to lowering the inspector into the excavation.
- Place all equipment, spoils, loose soil or rock and anything else that could potentially fall into the excavation at least 3 feet (1 meter) away from the edge of the excavation.
- Do not perform any work within 20 feet (6 meters) of the drilled pier excavation while the inspector is in the hole. This includes any drilling, blasting, casing installation or removal, moving equipment, etc.
- Utilize air monitoring to check for oxygen and combustible gasses.
- Always wear appropriate safety equipment including hard hat, hearing protection, safety harness and safety rope. Safety equipment is described in detail in the ADSC down-hole entry manual.
- **Always be aware of the conditions in the hole. If conditions change or dangerous situations occur such as increased water flow, the inspector should signal to exit the excavation immediately.** For this reason, it is critical that operators of the lifting and lowering equipment remain at the controls during the entire inspection.

Air monitoring is covered in detail in the ADSC down-hole entry manual in the Appendix. All drilling contractors should have an air monitoring device capable of monitoring oxygen and combustible gases. There are also air monitoring devices available that can monitor other less common gasses. Before entering a drilled pier excavation, the air should be checked for either inadequate or a surplus of oxygen and the presence of combustible gasses.

1. Oxygen
   Typical breathable air contains between 19.5% and 22.5% oxygen. The concentration of oxygen in the air can not be detected by sight, taste or smell. Oxygen deficiency is more likely than oxygen surplus. If there is less than 19.5% oxygen in the air, a person may experience "hypoxia", or lack of adequate oxygen. Signs of hypoxia include headaches, shortness of breath, disorientation, and a blueness of the skin around the mouth and fingers. If there is more than 22.5% oxygen in the air, a person may notice dizziness, nausea and disorientation. An oxygen surplus is also a hazard because of the possibility for combustion, fire

and explosions. Before measuring the oxygen in the excavation, the monitor should be calibrated on fresh air (20.8% oxygen).

2. Combustible Gasses
   Hydrocarbons, compounds containing carbon and hydrogen, are the most common combustible gasses found in subsurface environments. Methane is the most common hydrocarbon. Hydrocarbons are odorless, colorless and tasteless. Combustible gas concentrations are measured in terms of percent of the Lower Explosive Limit (LEL). By default, most air monitoring devices will begin sounding an alarm when the LEL level reaches 10%. However, many air monitoring devices will allow the user to change the LEL level at which the alarm will begin sounding. The ADSC down-hole entry manual in the Appendix recommends not entering a drilled pier excavation if the LEL level exceeds 5%.

Not following safety guidelines is dangerous and unwise. Down-hole inspection safety is not a decision that should be made by the drilling contractor for the inspector; down-hole inspection safety is a decision that each inspector should make for himself or herself.

D. Methods for Checking Bearing Capacity

The majority of the drilled piers constructed for NCDOT are designed for end bearing. As a result, it is important to check that the end bearing conditions at the tip elevations are as required. The subsurface investigation includes borings that are approximately 6 inch (150 mm) diameter holes with approximately 2 inch (50 mm) diameter samples and 1 to 2 borings per bent that are probably not located at the exact drilled pier locations. The subsurface conditions can vary widely between borings and may not accurately depict the conditions that are encountered when drilling a much larger hole for the drilled pier (minimum 3 feet, 914 mm diameter). The special provision lists three methods for checking bearing; visual, test hole and standard penetration test (SPT). The method for checking bearing will depend on the subsurface conditions and the drilling methods. For example, if an excavation is not dewatered, it may not be possible to check bearing visually.

If the tip of the drilled pier is in rock, the special provision requires a 1-1/2 inch (38 mm) diameter test hole to a depth of 6 feet (1.83 meters) below the tip elevation. The drilled pier contractor usually drills the test hole by entering the excavation. The purpose of the test hole is to check for soft seams and voids below the tip elevation with a “feeler” rod. A typical feeler rod consists of a long steel rod 5/8 inches (1.6 cm) diameter with a perpendicular tip projecting 1.2 inches (3.1 cm) outward at the lower end. The thickness of the tip normally tapers from 1/8 inch to1/4 inch (0.3 to 0.6 cm). Figure 14 illustrates a feeler rod with a close up view of the tip. In general, a test hole is recommended for each drilled pier in rock regardless of the number of drilled piers in a bent or the number of bents. If the test hole is waived, this should be approved by either the area bridge construction engineer or the Geotechnical Engineering Unit.

FIGURE 14 – Feeler Rod with Close Up View of Tip

If the tip of a drilled pier is in either weathered rock or soil, the soils engineer may include standard penetration tests (SPT) in the contract. "SPT Testing" is a pay item, measured per test. SPT is the same test performed during the subsurface investigation. Consequently, the SPT blow counts shown on the subsurface cross sections are comparable to the SPT blow count obtained from the bottom of the drilled pier excavation. The special provision describes how to perform the SPT in the open excavation and requires the test in accordance with ASTM D1586. This ASTM standard for the SPT is included in the Appendix. Section 7.2 of ASTM D1586 describes how to drive the sampler and when it is acceptable to terminate driving before reaching the 18 inches (0.45 meters). The Geotechnical Unit has revised Section 7.2 for NCDOT practice to the following:

Drive the sampler with blows from the 140-lb. (63.5-kg) hammer and count the number of blows applied in each 6-in. (0.15-m) increment until one of the following occurs:
1) The sampler is advanced the complete 18-in. (0.45-m) interval.
2) A total of 100 blows have been applied in any 2 consecutive 6-in. (0.15-m) intervals.
3) A total of 50 blows have been applied with < 3-in. (.08-m) penetration.

The drop height of the hammer is 30 inches (0.76 meters). In general, this revision requires driving the sampler beyond the ASTM requirements. The reason for this is to insure that the sampler is not on a rock lens or over a soft layer.

The primary advantage of the SPT is the test can be performed without entering the excavation. Another advantage is the SPT blow count can be directly correlated to bearing capacity. Based upon an empirical correlation, the soils engineer will provide the required SPT blow count for each project with the review of the drilled pier construction sequence plan, if SPT is required. The SPT may be performed by either a consultant or the drilling contractor. Figures 15 and 16 are pictures of a SPT being performed by a consultant and a drilling contractor.

FIGURE 15 – SPT performed by Consultant

E. Methods for Checking Cleanliness

The special provision defines a clean drilled pier excavation bottom as “a minimum of 50% of the bottom area has less than ½ inch (13 mm) of sediment and no portion of the bottom area has more than 1 ½ (38 mm) of sediment as determined by the Engineer.” If the pier excavation bottom is not clean prior to placing the reinforcing steel, a “soft bottom” may occur. A soft bottom is the result of excessive sediment at the tip of the drilled pier and can cause unacceptable settlement and reduced end bearing. The special provision lists three methods for checking bottom cleanliness; visual, steel probe and shaft inspection device (SID). Similar to checking bearing, the method for checking cleanliness will depend on the subsurface conditions and the drilling methods. The primary influence affecting bottom cleanliness is the drilling contractor’s cleaning methods.

FIGURE 16 – SPT performed by Drilling Contractor

In many situations, it is necessary to inspect for cleanliness through water or slurry. One method to do this is a steel probe rod. The special provision details the required specifications for a steel probe rod to be supplied by the contractor. Figure 17 is a picture of a steel probe rod. It is important that the contractor provide a steel probe rod in accordance with the special provision in order to develop and maintain consistency around the state. *A weighted tape is not acceptable for checking cleanliness because it will generally indicate less sediment than what is actually present*.

The department currently owns two shaft inspection devices (SIDs). A SID is a remotely operated camera capable of observing bottom conditions and measuring sediment underwater and slurry. Figure 18 is a picture of a SID. Images are transmitted back to a video unit for viewing and recording. Figure 19 is a picture of a video unit for the SID. In general, five locations are inspected. In accordance with the special provision, three or more of the locations shall have less than a ½ inch (13 mm) of sediment and the remaining locations shall have less than 1 ½ inches (38 mm) of sediment. If the cleanliness inspection fails, subsequent inspections are required until the cleanliness meets the specifications. The Materials and Tests Unit maintains the SIDs. The Geotechnical Engineering Unit coordinates inspections with the SIDs. One SID is based in Leland (near Wilmington) with the Section Materials Specialist for Divisions 2 and 3 of the Material and Tests Unit. The other SID is based in Raleigh at the main office of the Materials and Tests Unit. "SID Inspection"

FIGURE 17 – Steel Probe Rod

FIGURE 18 – Shaft Inspection Device (SID)

FIGURE 19 – Video Unit for SID

is a pay item, measured per drilled pier. The SID is not measured per inspection because, as described above, the cleanliness is primarily a function of the drilling contractor's cleaning methods.

It can be very difficult to determine whether the bottom meets the cleanliness requirements in the special provision with the steel probe rod even for an experienced inspector. Visual is the best method for checking cleanliness but is not always possible. If it is not possible to enter the excavation, the SID is the best method for inspecting the cleanliness of the drilled pier excavation bottom. The SID enables the cleanliness inspection to become a relatively straightforward "yes" or "no" answer. However, due to the limited availability of the SIDs, it is generally used only for the first few drilled pier excavations that are not hand cleaned on a project. This allows the inspector to gage the drilling contractor's cleaning methods and compare the steel probe rod results to the SID results. Once the drilling contractor's cleaning methods are established and the inspector develops confidence in checking cleanliness with the steel probe rod, the SID can be discontinued.

F. Slurry Testing

In order for slurry to perform properly the pH, density and viscosity must be maintained within certain ranges. Normally, the drilling contractor checks these properties. However, it is good practice for the inspector to closely observe the contractor's testing methods and perform occasional comparison tests. The slurry testing procedures for viscosity, density and sand content are included in the

Appendix. The Geotechnical Engineering Unit also has an instructional video explaining slurry testing methods. Contact the Geotechnical Engineer Unit to borrow this video or for further information about slurry testing procedures. Division 3 and the Geotechnical Engineering Unit have slurry testing kits. Figure 20 is a picture of a slurry testing kit with the pH paper, Marsh cone (for viscosity), density balance and the American Petroleum Institute (API) sand content kit labeled. The slurry testing frequency and criteria are listed in the special provision.

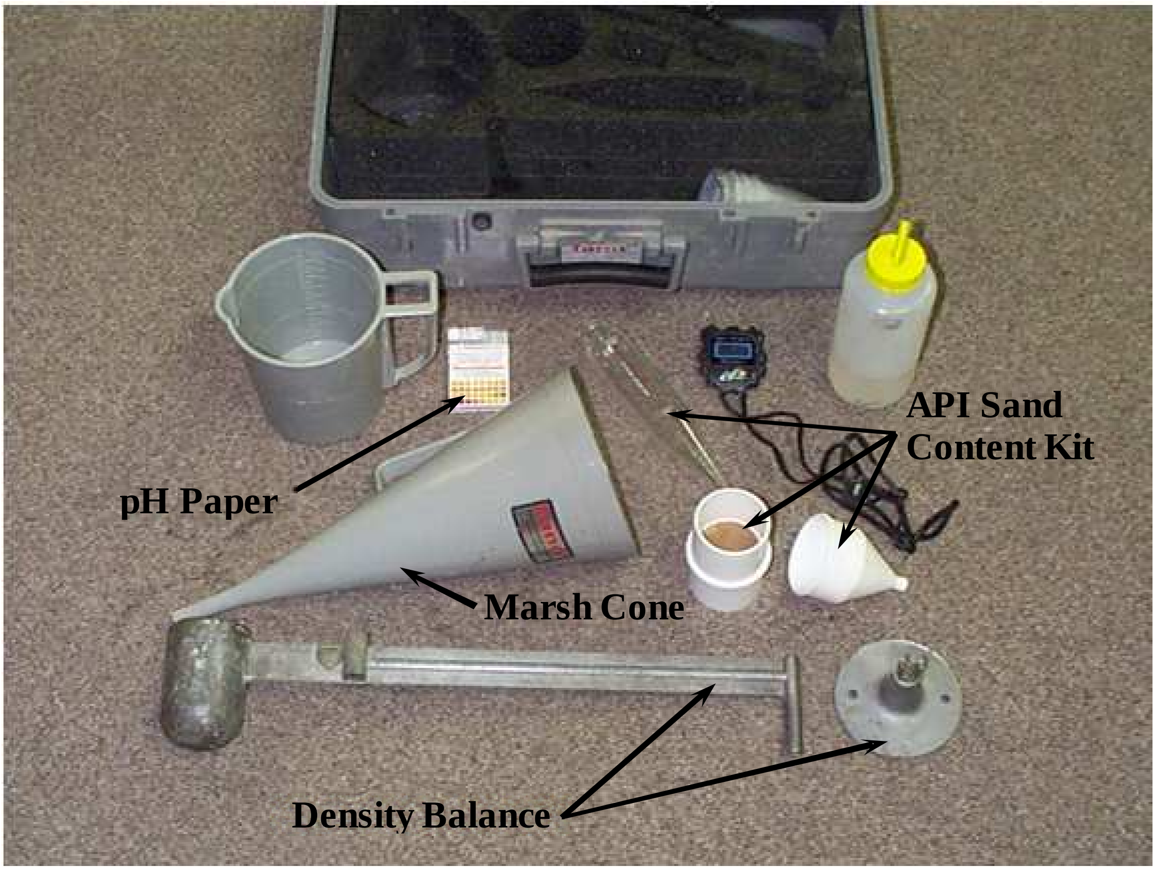

FIGURE 20 – Slurry Testing Kit

The pH is an indicator of the degree of acidity or alkalinity of the slurry and is primarily a function of the mixing water used. A low pH can cause the bentonite to fall out of suspension. The special provision requires that written approval from the bentonite supplier for the proposed mixing water source be submitted with the drilled pier construction sequence plan. In addition, this approval will normally include the amount of soda ash or other hardness reducer required to adjust the pH, if necessary.

The slurry should meet the pH, density and viscosity requirements in the special provision after hydration and before it is first introduced into the drilled pier excavation. For this reason, the first sample should be taken from the slurry tank. All remaining samples should be taken from the excavation as detailed in the special provision. As drilling proceeds, the unit weight, sand content and often the viscosity will increase as the slurry picks up clay, silt and sand.

The 2 % sand content may not be met until after the slurry is desanded. If necessary, the drilling contractor will desand the slurry by recirculating the slurry through a desanding unit. Figure 21 is a picture of a vibratory desanding unit. A high sand content is undesirable immediately before placing the reinforcing steel because all the sand may not be held in suspension before the slurry can be displaced by fluid concrete. If the sand settles and is deposited onto the clean bottom of a drilled pier excavation, reduced end bearing capacity will result.

FIGURE 21 – Vibratory Desanding Unit

G. Rock Socket

A note on plans may require a minimum penetration into rock, in other words, a rock socket. Typically, a rock socket is required in highly variably subsurface conditions when it is difficult for the soils engineer to reasonably determine the rock elevation or quality at each drilled pier location. In Section 1.0, the special provision states that the rock socket will be "as directed by the Engineer." The reason for this is that the pay item length for drilled pier not in soil does not necessarily correlate to the rock socket length. For example, subsurface conditions may indicate a variable amount of weathered rock overlying hard crystalline rock. In the field, the excavation may be in weathered rock at the tip elevation and from a pay item standpoint qualify for the minimum rock socket length. However, the soils engineer may have intended for the rock socket to be hard crystalline rock which is much stronger than the weathered rock the drilling contractor was excavating as drilled pier not in soil. Whenever a rock socket is required, the soils engineer will direct the inspector in how to verify the rock socket.

H. Drilled Pier Not in Soil Verification

Regardless of whether a rock socket is required, the inspector should verify that the elevation of drilled pier not in soil (if applicable) is reasonably close to the rock elevation shown on the borings. This is very important. If the drilled pier not in soil begins substantially deeper than the rock elevation shown on the borings, the soils engineer may require a deeper drilled pier for adequate lateral stability. In the opposite sense, if a drilled pier not in soil begins substantially higher than the rock elevation shown on the borings, this should be discussed with the area bridge construction engineer and the Geotechnical Engineering Unit. If this situation is not addressed early on in the project, large overruns in the drilled pier not in soil quantity can occur. When weathered rock is present, the drilled pier not in soil may begin at any elevation within the weathered rock depending on the size and condition of the drill rig, drilling equipment used and the degree of weathering in the rock. As a result, it is not necessary to discuss a higher drilled pier not in soil elevation in weathered rock with the area bridge construction engineer and the Geotechnical Engineering Unit unless a significant quantity overrun is anticipated.

Figure 22 shows example borings similar to what would be included on a typical cross section with the subsurface information. The old and new legend is shown with soil (and SPT blow counts), weathered rock and different types of rock labeled. In general, hard rock, crystalline rock, non-crystalline and sometimes sedimentary rock may be considered drilled pier not in soil.

I. Concrete Testing

One set of cylinders for 28-day strength is required per truck. Additional sets may be made for early strength determination. Each load should be tested for air, slump and temperature. Entrapped air should not exceed 7½ %. The special provision requires that the drilled pier concrete be non air-entrained. Excess air can result from air-entrained concrete or combination of admixtures. The concrete temperature may not exceed 90 degrees and the air temperature at the time of placement must be 35 degrees or higher in accordance with Section 1000-4(D) of the Standard Specifications.

Low slump drilled pier concrete may keep the concrete from flowing around the rebar and trap air or water in the pier and a high slump may result in excessive segregation or bleeding. The special provision requires two different slumps depending on the concrete pour type (wet or dry). A 7 to 9 inch (175 to 225 mm) slump is required for wet pours. A 5 to 7 inch (125 to 175 mm) slump is required for dry pours. A lower slump for a dry pour reduces the chances of segregation when the concrete is placed by free fall. A higher slump for a wet pour improves the flow of the concrete through the tremie or pump pipe and into the in place concrete. Drilled pier concrete with slumps outside the limits in the special provision can result in problems and should be corrected or rejected.

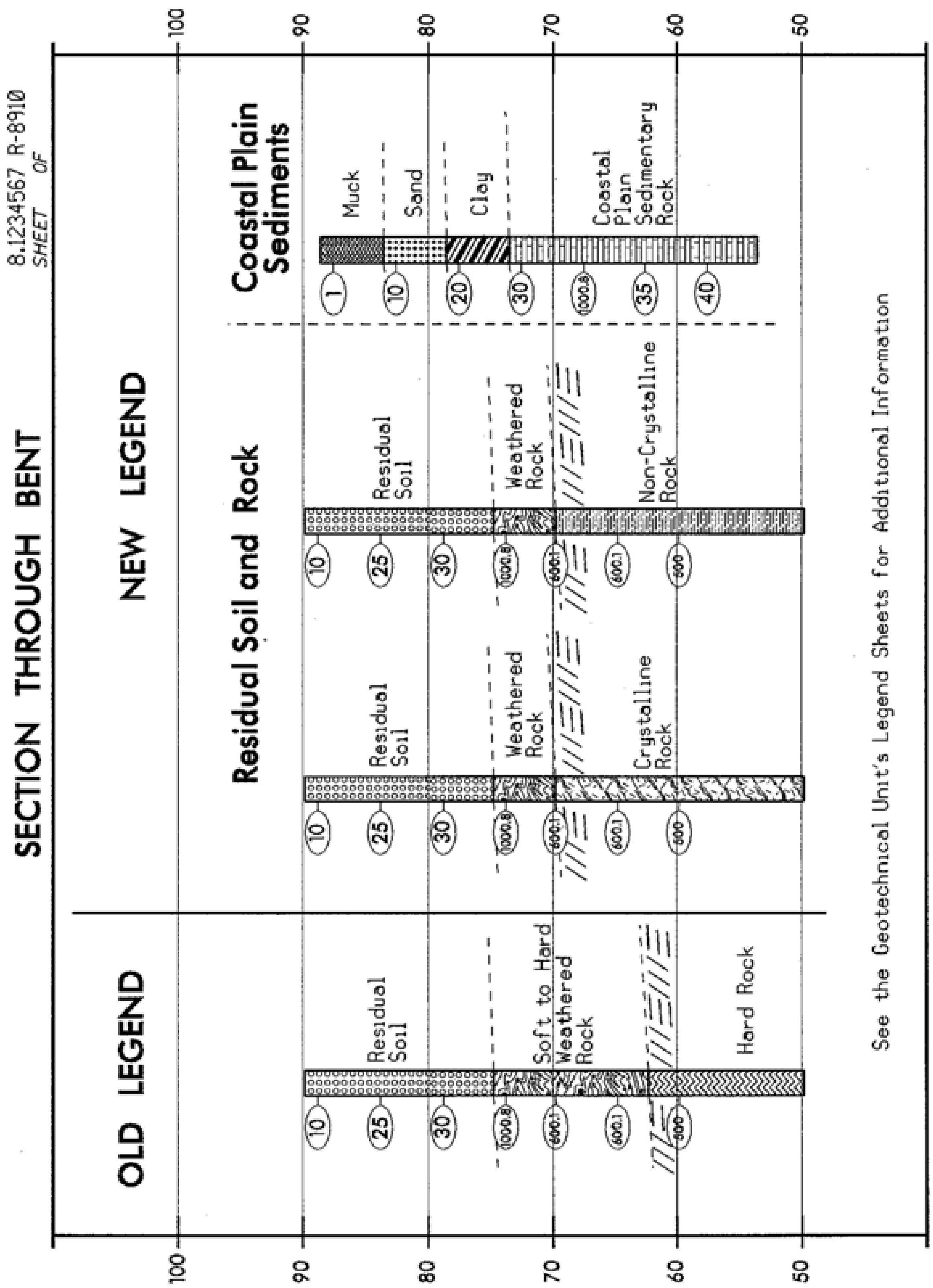

Figure 22 – Example Borings for a Cross Section

J. Inspection Forms

Inspection forms are crucial to the Geotechnical Engineering Unit. The soils engineer can not be present at each project. Typically, the inspection forms are the only information the soils engineer will receive about the construction of the drilled piers. Many times, inspectors are the only department representatives on site during the construction of the drilled piers. The inspection forms are written records of what occurred. The forms should be filled out completely, thoroughly and as accurately as possible. Comments and occurrences, no matter how insignificant they may seem, should be recorded. The Geotechnical Engineering Unit believes more information is always better than less. If there is a problem with a drilled pier, the inspection forms may be the only detailed construction records available.

Current inspection forms are available on the DOH website under "Geotechnical Engineering Unit Forms" in "Industry Links". Copies of the most current forms at the time of printing this manual are also included in the Appendix. Before beginning a drilled pier project, the website should be checked for updated inspection forms.

<u>Drilled Pier Inspection Form</u>

Drilled pier inspection forms for both casing and slurry method are available. The inspector should fill out the appropriate form and transmit it to the Geotechnical Engineering Unit. Specific questions concerning how to fill out these forms should be directed to the Geotechnical Engineering Unit.

The purpose of recording the "Theoretical Volume" versus the "Volume Placed" is to verify that these volumes are approximately equal. The most common error occurs when recording the "Theoretical Volume". **Unless the drilled pier is constructed with the exact diameter shown on the plans and to the exact tip elevation shown on the plans, the concrete volume shown on the plans is NOT the theoretical volume.** The theoretical volume normally must be calculated in the field based upon telescoping casing, if applicable, and the actual drilled pier diameter and length. For example, three levels of telescoping casing would require the sum of calculations for three different lengths of drilled piers with three different diameters. Even a non-telescoped drilled pier constructed with permanent casing in rock requires a calculation of the theoretical volume since the inside diameter of the permanent casing and the drilled pier diameter in the rock is slightly smaller than designed. In order to assist in these calculations, a table entitled "Concrete Volumes" is provided in the Appendix. This table lists concrete volumes per unit length for drilled pier diameters from 34 inches (864 mm) to 96 inches (2438 mm) in 2 inch (50 mm) increments.

<u>Drilled Pier Drilling Log</u>

Per Section 2.0 of the special provision, the drilling contractor should "Maintain a drilling log during the drilled pier excavation and provide it to the Engineer. Include in the log information such as top and bottom elevation of each stratum encountered, drilling tools used and drilling time in each stratum and material descriptions of each soil and rock layer." The drilling contractor must fill out the drilling log and provide it to the inspector when the drilling is complete. Review and attach this form to the corresponding drilled pier inspection form to be sent to the Geotechnical Engineering Unit.

SID Inspection Form

The personnel performing the SID inspection will normally provide this form. One form should be filled out for each inspection. After completing the inspection(s), attach this (these) form(s) to the corresponding drilled pier inspection form to be sent to the Geotechnical Engineering Unit.

Concrete Curve

Section 6.0 of the special provision states "For drilled piers constructed with slurry or as directed by the Engineer, record a graphical plot of the depth versus theoretical concrete volume and actual measured concrete volume for each drilled pier and provide it to the Engineer when finished placing concrete." A "graphical plot of the depth versus theoretical concrete volume and actual measured concrete volume" is commonly called a concrete curve. Basically, a concrete curve is used to compare the actual concrete level to where it is suppose to be during the concrete pour. It is similar to recording the theoretical volume and volume placed on the drilled pier inspection forms except that instead of comparing the totals at the end of the concrete pour, the theoretical volume and volume placed are recorded and plotted throughout the pour. A form for plotting the concrete curve is included in the Appendix.

Figure 23 shows an example concrete curve plotted from a spreadsheet. The actual concrete level is measured after each truck with a weighted tape and plotted as the "measured" line. The theoretical concrete level is calculated for each load of concrete placed based upon the shaft dimensions and plotted as the "theoretical" line. If the drilled pier dimensions are as anticipated and all the concrete is placed in the excavation, the measured and theoretical line will be the same. However, normally there is a small difference between the two. If the measured line is below the theoretical line for a given length of pier, more concrete was placed than anticipated. This may be the result of rough uneven sidewalls of the excavation. If the measured line is above the theoretical line for a given length of pier, less concrete was placed than anticipated. This may be a potential problem such as an intrusion or a partially collapsed excavation. As shown in Figure 23, the concrete curve can also indicate where a potential problem occurred. Regardless of whether the measured is above the theoretical or visa versa, large differences between the lines may indicate problems and should be discussed with the area bridge construction engineer and the Geotechnical Engineering Unit.

Most drilling contractors will plot the concrete curve. However, as with slurry testing, it is good practice for the inspector to confirm the contractor's measurements and occasionally plot comparison concrete curves. In some cases, the soils engineer will require plotting concrete curves when slurry is not used because there is higher than normal potential for problems during the concrete pour. For example, concrete curves might be required for a long pier through fractured rock or caving soils with

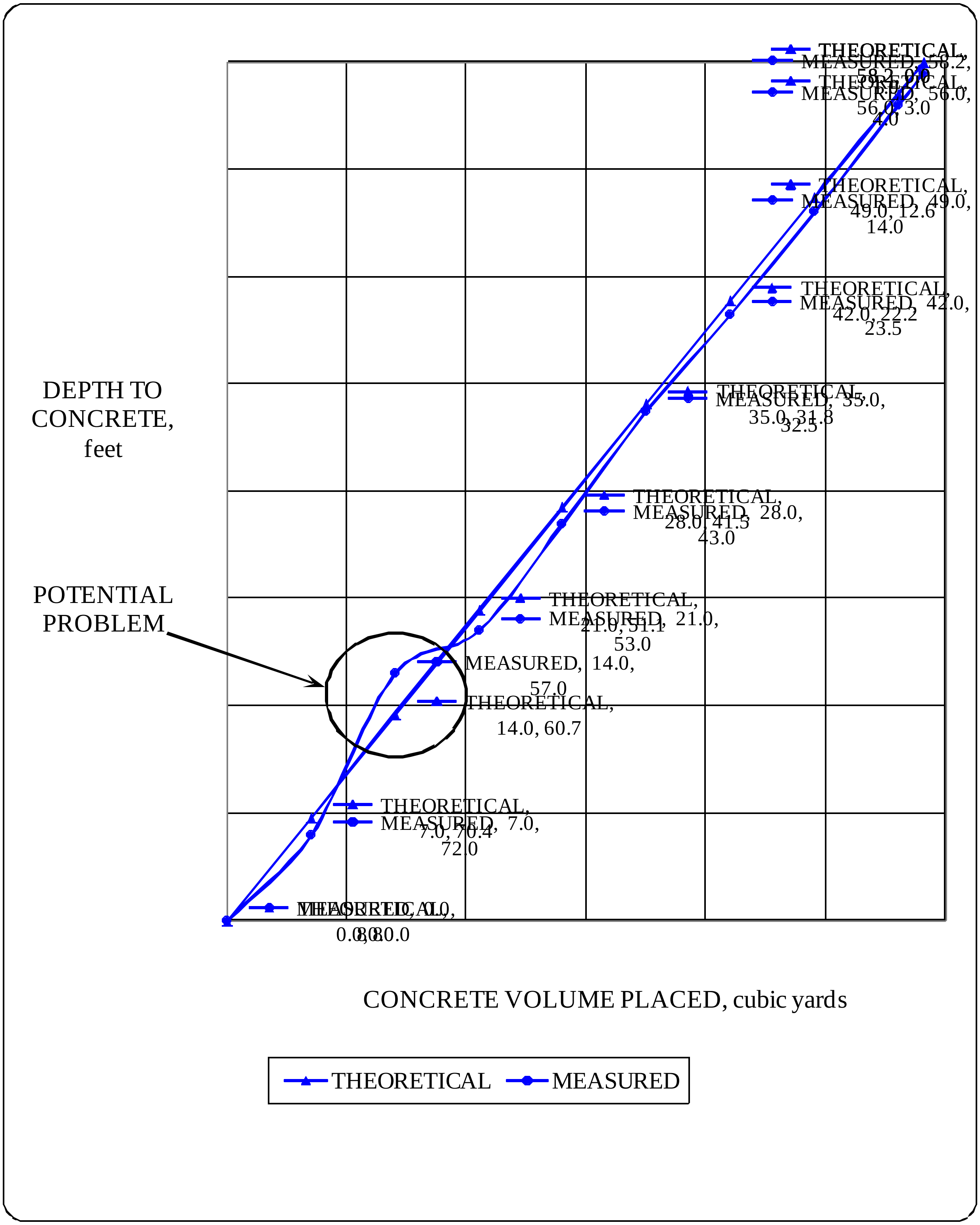

FIGURE 23 – Example Concrete Curve

telescoping temporary casings. If concrete curves are required for non-slurry drilled piers, the soils engineer will note such in the review of the drilled pier construction sequence plan. After completing the concrete pour, attach the concrete curve to the corresponding drilled pier inspection form to be sent to Geotechnical Engineering Unit.

V. Post Construction Testing

If problems occur during a concrete pour, the department may elect to perform further testing of the drilled pier. The Geotechnical Engineering Unit in coordination with the resident engineer and the Construction Unit will recommend the type and scope of testing depending on the severity and particulars of the situation. There are no foolproof testing methods available for investigating a drilled pier. Most test methods require some interpretation of the results. Rejection or acceptance of a drilled pier requires reviewing all the drilled pier construction information, design requirements and testing results. Because the drilled pier is almost entirely contained in the ground, further investigation of a drilled pier is similar to a mystery that involves collecting and considering all the clues. The test results are considered clues. Witness accounts and inspection forms are also considered clues. The following three sections describe the most common testing options employed by the department for further investigation of a drilled pier. They are listed in order of increasing cost and destructiveness to the pier.

A. Non-Destructive Testing (NDT)

The Geotechnical Engineering Unit performs sonic echo tests with a device called a Pile Integrity Tester (PIT). A PIT test involves sending a sonic wave down the pier by tapping the top of the pier with a hand held hammer. Figure 24 illustrates two soils engineers performing a PIT test. The wave is reflected from the tip of the pier back to the top and velocity versus time is measured with an accelerometer attached to the top of the pier. Based upon the anticipated diameter and length of the pier, the soil strata and a typical wave velocity in concrete, the records can indicate potential anomalies. The advantage of the PIT is that the test can be performed fairly rapidly and inexpensively without any internal intrusion to the pier.

However, the PIT has numerous disadvantages, some limitations and may be unreliable in some situations. PIT data can be difficult to interpret. In general, the defect must be fairly large and located below the top two to three pier diameters to be identified by the PIT. Smaller defects as well as the size and extent of defects are difficult to determine with the PIT. The FHWA drilled shaft manual (Publication No. FHWA-IF-99-025) recommends "…the sonic echo test should be considered to be only a very crude screening method that is capable of locating only major defects.…"

Section 8.0 of the special provision states that the engineer will choose which drilled piers will be PIT tested. When the engineer selects a drilled pier for PIT testing, the contractor is required to prepare the top of the drilled pier by grinding four areas down to exposed aggregate once the pier has been in place for 5 days and the concrete has achieved a concrete strength of 3000 psi (20.7 MPa). The form entitled "NDT

Preparation" located on the DOH website under "Geotechnical Engineering Unit Forms" in "Industry Links" shows how and where to grind the top of the pier.

FIGURE 24 – Pile Integrity Test (PIT)

A copy of this form is also included in the Appendix. The special provision also states that no separate payment will be made for NDT and that three days are required to analyze the test results.

B. Crosshole Sonic Logging (CSL)

When crosshole sonic logging (CSL) testing is included in the contract, either four [pier diameter of 5 feet (1524 mm) or less] or six [pier diameter greater than 5 feet (1524 mm)] tubes will be cast into the drilled piers in accordance with the CSL special provision. The standard Crosshole Sonic Logging Special Provision is included in the Appendix. CSL testing can also be performed through core holes. CSL tubes must have an inside diameter of 2 inches (50 mm), be Schedule 40 steel pipe and extend from 6 inches (150 mm) above the tip of the pier to at least 3 feet (1 meter) above the top of pier elevation. Figure 25 is a picture of drilled pier reinforcing steel with four capped CSL tubes.

CSL testing is performed by lowering a transmitter into one tube and a receiver into another. The transmitter repeatedly emits an acoustic signal and the receiver picks up that signal as they are lowered down the pier. The receiver signal can be examined to determine the travel time from one tube to the other. Anomalies are defined by a reduction in travel time. Typically, each perimeter pair of tubes and major principal axes pair of tubes are tested.

FIGURE 25 – CSL Tubes

The Geotechnical Engineering Unit should be consulted before commencing with any CSL testing. CSL testing is usually performed by private geotechnical engineering or testing firms. Basically, the CSL consultant is responsible for collecting and presenting the data. Figure 26 is a picture of CSL data acquisition equipment. Geotechnical Engineering Unit reviews and interprets the report and recommends either acceptance of the pier or further testing. Further testing may include retesting with CSL again or coring (see next section). If the results indicate a 20% or greater reduction in travel time, angle testing (source and receiver at different depths) is required. The results of angle testing are used to develop a three-dimensional picture of the drilled pier. This technique is known as tomography. CSL testing offers a significant advantage over the PIT since tomography can approximate the size and extent of defects.

As with any testing procedure, CSL has limitations. CSL only tests between the tubes such that the concrete area outside the reinforcement is not tested. Variations in concrete strength can affect travel times; higher strength concrete results in faster travel times. The concrete strength may meet the required 4500 psi (31.0 MPa) but variations above this strength can still result in anomalies in the CSL results. This is the reason for requiring a concrete strength of 3000 psi (20.7 MPa) before testing;

less variation is expected in older concrete. CSL testing also does not work if the tubes debond from the concrete. This is the reason for requiring steel tubes, filling

FIGURE 26 – CSL Data Acquisition Equipment

the tubes with water and testing within 30 days. All of these things will help prevent debonding before the CSL testing can be completed.

As of November 2001, all bridges designed with drilled piers will have CSL tubes and testing in the contract. CSL tubes and testing for drilled pier bridges designed prior to November 2001 were included in the contract at the discretion of the soils engineer. The tube size, manufacturer's certificate of compliance, the proposed method of installing the tubes and the CSL consultant should be submitted to the engineer, preferably with the drilled pier construction sequence plan. It is recommended that the CSL tubes be attached to the spirals and not the longitudinal bars so that concrete can flow more freely around the tubes. Payment for CSL is divided into two pay items; "CSL Tubes" per linear foot or meter and "CSL Testing" per pier. In general, CSL tubes are applicable for all drilled piers and CSL testing is applied to only the piers tested.

C. Coring

Coring has been used with limited success to investigate drilled piers. It is uncommon to find evidence of a defect with coring; it depends on the size and extent of the defect as well as just plain luck. Figure 27 is a picture of a core with a defect. This particular drilled pier had water flowing into the core hole. Coring is also performed to investigate for low strength concrete. Recovered cores can be cut and tested for compressive strength. If coring is performed after CSL testing, it is generally used to investigate a specific anomaly identified by the CSL testing.

FIGURE 27 – Core from Drilled Pier with Defect

When the Geotechnical Engineering Unit recommends coring, the number of holes, locations, depths and other requirements will be provided. PQ size core (core size 3.34 inches or 85 mm) is recommended so that the cores are large enough to be tested for compressive strength. In general, the core holes should be as close as possible to the inside of the reinforcement. Defects are less likely to occur in the center of a drilled pier. Figure 28 shows a cored drilled pier with the outer edge of the core hole 12 inches (300 mm) from the inside edge of the reinforcement. After the coring is complete, the core holes should be dewatered and monitored for water inflow. It is also possible to look at the core hole with NCDOT Geotechnical Unit's miniature remote controlled camera.

Sometimes, the reinforcement extending out of the drilled pier must be cut for access to perform the coring. If the drilled pier is accepted, the reinforcement is then mechanically spliced as approved by the Structure Design Unit. Also, the core holes must be dewatered and grouted if the drilled pier is accepted. The grout shall be an approved high strength grout with a minimum compressive strength of 4500 psi (31.0 Mpa). It is critical that the core holes are open (non-grouted) and access to the core locations is available until the drilled pier accepted; some defects require an extensive investigation.

Because coring provides a physical sample, it is a very good indication as to the physical character of the concrete. However, this indication is only for a small portion of the pier. Coring is also time-consuming and very expensive.

FIGURE 28 – Core Hole in Drilled Pier